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LINEWIDTH OF NONORIENTED POLYCRYSTALLINE HEXAGONAL FERRITES WITH LARGE MAGNETIC ANISOTROPY FIELDS

ISIDORE BADY

GILBERT McCALL

MARCH 1963

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UNITED STATES ARMY
ELECTRONICS RESEARCH AND DEVELOPMENT LABORATORY
FORT MONMOUTH, N.J.

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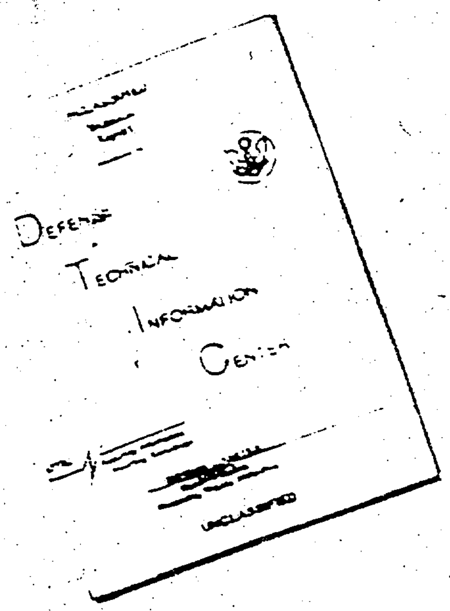

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March 1963

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LINEWIDTH OF NONORIENTED POLYCRYSTALLINE HEXAGONAL FERRITES WITH LARGE MAGNETIC ANISOTROPY FIELDS

Isidore Bady

Gilbert McCall

DA Task No. 3A99-15-006-02

Abstract

Theoretical calculations are made of the linewidth of nonoriented, polycrystalline, hexagon ferrites with large magnetic anisotropy fields, including both uniaxial and planar ferrites. The motivation for this work arises from an attempt to find an explanation as to why oriented polycrystalline uniaxial ferrites have been found to have, in general, much wider linewidth than that of planar ferrites.

The nonoriented ferrites are considered to be composed of crystallites whose C axes are randomly oriented over all possible solid angles. For a given biasing field, the solid angle Ω is calculated within which the C axis of a crystallite must lie in order that its resonant frequency will differ from the test frequency by a chosen amount. All crystallites within this angle are presumed to absorb energy equally; all other crystallites are presumed not to absorb any energy. The loss term of susceptibility is proportional to Ω, and a linewidth can be calculated. It is shown that the linewidth of a nonoriented uniaxial ferrite is considerably wider than the linewidth of a nonoriented planar ferrite. Since imperfect orientation is a major contributor to the linewidth of oriented hexagonal ferrite it is seen that imperfect orientation will affect the linewidth of uniaxial ferrites far more than that of planar ferrites. This is supported by test data which show that nonoriented planar ferrites can have a linewidth considerably narrower than the narrowest linewidth obtained with oriented uniaxial ferrites.

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LINEWIDTH OF NONORIENTED POLYCRYSTALLINE HEXAGONAL FERRITES WITH LARGE MAGNETIC ANISOTROPY FIELDS

INTRODUCTION

Data on the linewidth of oriented, polycrystalline, hexagonal ferrites with large magnetic anisotropy fields have shown that uniaxial ferrites (easy direction of magnetization along the C axis) have a considerably larger linewidth than that of planar ferrites (easy plane of magnetization perpendicular to the C axis). For example, in work performed at Philips[1] on uniaxial barium and strontium ferrites of magnetoplumbite structure with aluminum or titanium-cobalt substitutions, the linewidth varied over a range of 1600 to 3300 oersteds for materials with anisotropies ranging from 7000 to 52,000 oersteds. There was no strong correlation between linewidth and anisotropy field. In work done at Sperry[2] on uniaxial nickel-W compounds with cobalt substitutions, linewidth ranged from 2200-3000 oes for materials with anisotropies ranging from 7000 to 12,800 oersteds. On the other hand, in work performed by RCA on planar ferrites, a linewidth as low as 110 oersteds was obtained,[3] and a large number of compounds had a linewidth less than 500 oersteds.[4]

It is very unlikely that the large linewidth of polycrystalline uniaxial ferrites is due to the crystallite's linewidth. Though relatively little work has been done on single crystals of hexagonal ferrites, a linewidth of 50 oersteds was achieved on a single crystal of barium ferrite[5] and on a single crystal of aluminum substituted strontium ferrite.[6] A linewidth of 18 oersteds was obtained on a single crystal of planar ferrite Zn_2Y.[7] However, there has been considerably more research done on single crystals of Zn_2Y ferrites than on those of uniaxial ferrites to reduce linewidth.

A major contribution to the linewidth of oriented hexagonal ferrites, both of uniaxial and planar types, was considered to be imperfect orientation. It was therefore desirable to study the extreme case of imperfect orientation, i.e., completely nonoriented materials, and compare the theoretically calculated linewidths of the uniaxial and planar ferrites for this case.

METHOD OF CALCULATION

This section contains only a brief outline of the method used to calculate the linewidth of the nonoriented uniaxial and planar ferrites. A detailed procedure is included in the appendix.

The nonoriented ferrite was assumed to be composed of small, single-domain crystallites whose C axes were randomly oriented over all possible solid angles. It was further assumed that the crystallites did not interact with each other. Demagnetizing factors were disregarded for the sake of simplicity.

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Let us consider a resonant cavity containing the nonoriented ferrite. A biasing field is applied in a direction perpendicular to the rf magnetic field in the cavity. The resonant frequency of each crystallite will be determined by its anisotropy field, the biasing field, and the angle ψ its C axis makes with the biasing field. At one particular angle ψ_r for a given biasing field, the resonant frequency of the crystallite will be exactly the same as the test frequency and have the maximum interaction with the cavity. As the angle of the C axis departs from ψ_r, the resonant frequency becomes increasingly different from the test frequency, and the interaction with the cavity decreases. We calculate the angles ψ_1 and ψ_2 between which a crystallite must lie in order that its resonant frequency will differ from the test frequency by no more than a chosen amount. All crystallites within this angle are presumed to absorb energy equally; all other crystallites are presumed not to absorb energy. Let Ω be the solid angle subtended between the cones defined by ψ_1 and ψ_2. The loss term of magnetic susceptibility is proportional to Ω, and therefore a plot of Ω vs biasing field is a plot of the relative value of χ'', the loss term of susceptibility, vs biasing field. The linewidth is readily determined from such a curve.

DISCUSSION

A plot of χ'' (relative) for a nonoriented uniaxial ferrite is shown in Fig. 1, and plots for nonoriented planar ferrites are shown in Fig. 2. The abscissa in both figures is the shifted biasing field H_o-H_r, where H_o is the applied biasing field and H_r is the biasing field required for ferromagnetic resonance for a crystallite whose easy direction is parallel to the biasing field (for the uniaxial ferrite) or whose easy plane is parallel to the biasing field (for the planar ferrite).

A comparison of Fig. 1 and 2 shows that the linewidth of the nonoriented uniaxial ferrite is indeed very much larger than that of the planar ferrite. The most suitable comparison is between curve I of Fig. 2 and the curve in Fig. 1, since both have approximately the same value of anisotropy field and the same value of H_r. We note that the linewidth of the uniaxial ferrite is almost five times that of the planar ferrite.

The relatively narrow linewidth of nonoriented planar ferrites has been confirmed experimentally. Schlömann[8] has reported a linewidth of 500 oersteds for a nonoriented zinc Y. Of six nonoriented planar ferrites measured here three had linewidths of 1500 oersteds or less. It is interesting to find that completely nonoriented planar ferrites can have a linewidth narrower than the narrowest linewidth that has up to now been obtained with oriented polycrystalline uniaxial ferrites.

An understanding as to why the linewidth of nonoriented uniaxial ferrites is so much greater than that of nonoriented planar ferrites can be obtained from the following reasoning. The magnitude of Ω and hence the magnitude of the loss term of the susceptibility are proportional to two factors. Factor 1 is the magnitude of $|\psi_1 - \psi_2|$; factor 2 is the solid angle

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Ω_Δ subtended between the cones defined by ψ_r and $\psi_r + \Delta\psi_r$ where $\Delta\psi_r$ is a small increase in ψ_r.

Let us consider the variation of the two factors as a function of biasing field. Factor 1 is maximum when the biasing field is such that crystallites that are at ferromagnetic resonance are those whose easy direction of magnetization, or easy plane of magnetization (as applicable), is parallel to the biasing field. This biasing field has previously been designated as H_r. Factor 1 decreases as the biasing field is increased byeond H_r. Thus, factor 1 is relatively large when ψ is close to 0° for the uniaxial ferrites and close to 90° for the planar ferrites.

The solid angle subtended between the cones defined by ψ_r and $\psi_r + \Delta\psi_r$ is proportional to $\sin \psi_r$. Thus, factor 2 is small for biasing fields close to the H_r for uniaxial ferrites and increases as the biasing field is increased beyond H_r. In the case of planar ferrites, factor 2 is large for biasing fields close to H_r and decreases as the biasing field is increased beyond H_r.

Thus, in the case of uniaxial ferrites, as the biasing field is increased beyond H_r, factor 1 decreases and factor 2 increases. This tends to reduce the dependence of Ω on H_r as the biasing field is increased beyond H_r, and results in a relatively broad linewidth. In the case of the planar ferrites, however, both factors are large in the vicinity of H_r, and both decrease as the biasing field is increased beyond H_r. Thus, there is a relatively sharp peak of Ω in the vicinity of H_r, and this results in a relatively narrow linewidth.

CONCLUSIONS

Theoretical calculations show that nonoriented uniaxial ferrites have a much wider linewidth than that of nonoriented planar ferrites. Thus, the imperfect orientation that will inevitably occur when processing oriented polycrystalline hexagonal ferrites will have a greater effect on broadening the linewidth of uniaxial ferrites than that of planar ferrites. This explains at least part of th reason why oriented planar ferrites generally have a much narrower linewidth that that of oriented uniaxial ferrites. In fact, a number of completely nonoriented planar ferrites were prepared which have a substantially narrower linewidth than the narrowest linewidth achieved so far with polycrystalline oriented uniaxial ferrites.

REFERENCES

1. "Hexagonal Magnetic Materials for Microwave Applications," Final Report. Contract DA 36-039 SC-6527[illegible]. Philips Laboratories, Irvington-On-Hudson, New York, July 1961.

2. "Theoretical and Experimental Investigation to Determine the Microwave Characteristics and Applications of Hexagonal Magnetic Oxides to Microwave Circuitry," Technical Report, Contract AF 30 (602) [illegible], Sperry Microwave Electronics Company, Clearwater, Florida (December 1961).

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3. "Hexagonal Magnetic Compounds," Quarterly Report No. 6, Contract DA36-039 SC-87433, RCA Laboratories, Princeton, N. J. (December 1962).

4. "Hexagonal Magnetic Compounds," Final Report, Contract DA36-039 SC-78288, RCA Laboratories, Princeton, N. J. (June 1961).

5. Bady, Collins, DeBitetto and DuPré, "Ferromagnetic Linewidth of Single Crystals of Barium Ferrite ($BaFe_{12}O_{19}$)," Proceedings of the IRE, Vol. 58, p. 2033 (December 1960).

6. "Hexagonal Magnetic Materials for Microwave Applications," Final Report, Contract DA36-039 SC-78071, Philips Laboratories, Irvington-On-Hudson, N. Y. (July 1961).

7. Tauber, Savage, Gambino, and Whinfrey, "Growth of Single Crystal Hexagonal Ferrites Containing Zn," Journal of Applied Physics, Supplement to Vol. 33, No. 3, p. 1381 (March 1962).

8. Schlömann and Jones, "Ferromagnetic Resonance in Polycrystalline Ferrites with Hexagonal Crystal Structure," Journal of Applied Physics, Supplement to Vol. 30, No. 4, p. 177 (April 1959).

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APPENDIX: CALCULATION OF THE LINEWIDTH OF NONORIENTED HEXAGONAL FERRITES

In calculating the linewidth of nonoriented hexagonal ferrites, it was assumed that the ferrite was composed of small, single-domain, crystallites, whose C axes were randomly oriented over all possible solid angles. It was further assumed that the crystallites did not interact with each other. Demagnetizing factors were disregarded for the sake of simplicity.

RESONANCE EQUATION FOR CRYSTALLITES

Uniaxial Ferrites

In order to calculate the linewidth of nonoriented polycrystalline ferrites, it is necessary to determine the resonance equation for a single crystallite. This will first be done for a uniaxial ferrite.

The first step is to determine the equivalent magnetic field due to the anisotropy. Let us consider the crystallite shown in Fig. 3. The C axis is oriented along the Z direction. The equilibrium position for the magnetization is parallel to the C axis. When the magnetization is displaced from its equilibrium position by an angle θ, the energy stored is shown in the following equation:

$$E = K \sin^2 \theta \tag{1}$$

where the dimensions of E and K are energy per unit volume. K is called the anisotropy constant.

The magnitude of the torque per unit volume due to the anisotropy can be determined by differentiating the above equation. This yields

$$T_a = 2K \sin \theta \cos \theta. \tag{2}$$

The above torque is due to the crystallographic properties of the ferrite. Let us postulate an equivalent magnetic field H_{eq} that will exert the same torque. H_{eq} is clearly oriented parallel to the Z axis, and will be taken as pointing in the positive Z direction. Since, in general, the torque due to a magnetic field is equal to the product of the magnetic field, the magnetic moment, and the sine of the angle between the magnetic field

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and the magnetic moment, the magnitude of the torque per unit volume due to H_{eq} is given by

$$T_{eq} = H_{eq} M_s \sin\theta. \qquad (3)$$

Equating T_a and T_{eq} gives

$$H_{eq} = \frac{2K}{M_s} \cos\theta. \qquad (4)$$

The term $2K/M_s$ is generally designated as H_a, the anisotropy field. From Eq. (4), we note that H_a is equal to H_{eq} for small values of θ. From Fig. 3, we note that $\cos\theta$ is the ratio of the z component of magnetization to the total magnetization, i.e., $\cos\theta = M_z/M_s$. Thus, we can write Eq. (4) as,

$$\bar{H}_{eq} = H_a \frac{M_z}{M_s} \hat{z}. \qquad (5)$$

The bar above H_{eq} designates a vector quantity, and the caret above the z, a unit vector.

Let us now determine the resonance equation with static biasing fields of $H_x \hat{x}$ and $H_z \hat{z}$. For this case, the dynamic equation of motion,

$$\frac{1}{\gamma} j\omega \bar{m} = \bar{M} \times \bar{H} \qquad (6)$$

[illegible]

$$\frac{1}{\gamma} j\omega \bar{m} = [(M_x - m_x)\hat{x} + m_y \hat{y} + (M_z + m_z)\hat{z}]$$

$$\times [H_x \hat{x} + [illegible] + \frac{H_a}{M_s}(M_z + m_z)\hat{z}]. \qquad (7)$$

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Capital letters represent dc components and small letters rf components. Expanding the above equation yields three equations:

$$j\frac{\omega}{\gamma} m_x - m_y \left(H_z + H_a \frac{M_z}{M_s} \right) = 0 \qquad (8a)$$

$$m_x \left(H_z + H_a \frac{M_z}{M_s} \right) + j\frac{\omega}{\gamma} m_y + m_z \left(H_a \frac{M_x}{M_s} - H_x \right)$$
$$+ M_z H_x - M_x H_z - H_a \frac{M_x M_z}{M_s} = 0 \qquad (8b)$$

$$m_y H_x + j\left(\frac{\omega}{\gamma}\right) m_z = 0. \qquad (8c)$$

In the above equations, products of two rf terms were disregarded. Equation (8b) contains a group of rf terms and a group of dc terms, each of which must be equated to zero separately. Considering the dc terms only, and defining [illegible] $= M_z/M_s$; we can readily derive,

$$[illegible] \qquad (9)$$

The above equation [illegible] equation for the conservation of [illegible]

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The resonance equation can be obtained by setting the determinant of Eq. (8) to zero, including only the rf terms, i.e.,

$$\begin{vmatrix} \frac{j\omega}{\gamma} & -(H_z+\alpha_z H_a) & 0 \\ H_z + H_a\alpha_z & \frac{j\omega}{\gamma} & \alpha_x H_a - H_x \\ 0 & H_x & \frac{j\omega}{\gamma} \end{vmatrix} = 0. \tag{11}$$

This yields

$$H_x\left(H_x-\alpha_x H_a\right)+\left(H_z+\alpha_z H_a\right)^2=\left(\frac{\omega_r}{\gamma}\right)^2. \tag{12}$$

We use the notation ω_r in Eq. (12) instead of ω to designate that this is the frequency at which resonance will occur for given values of H_a, H_x, H_z.

Planar Ferrites

In determining the equivalent field due to the anisotropy, Fig. 3 can be used. The easy plane of magnetiziation will be taken as the YZ plane; hence, the equilibrium position of the magnetization is in the YZ plane; i.e., $\theta = 90^\circ$. Equation 1 applies to planar ferrites too. However, since the energy is at a minimum at $\theta = 90^\circ$, K is negative for planar ferrites. Corresponding to Eq. (2), we have

$$T_a = 2|K| \sin\theta \cos\theta. \tag{13}$$

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Let us now postulate an equivalent magnetic field H_{eq} that will exert the same torque. H_{eq} will clearly be oriented in the YZ plane, and the magnitude of the torque due to H_{eq} is given by

$$T_{eq} = H_{eq} M_s \cos \theta . \tag{14}$$

Equating T_a and T_{eq} gives

$$H_{eq} = \frac{2K}{M_s} \sin \theta = H_a \sin \theta \tag{15}$$

where we have written H_a for $2K/M_s$.

H_{eq} is oriented along the component of magnetization in the YZ plane; i.e., along M_{yz}. We can therefore write

$$\begin{aligned} H_{eq} &= H_a \sin \theta \left[\frac{M_y}{M_{yz}} \hat{y} + \frac{M_z}{M_{yz}} \hat{z} \right] \\ &= H_a \left[\frac{M_y}{M_s} \hat{y} + \frac{M_z}{M_s} \hat{z} \right]. \end{aligned} \tag{16}$$

Let us now determine the resonance equation with static biasing fields of $H_x \hat{x}$ and $H_z \hat{z}$. The dynamic equation of motion becomes

$$\begin{aligned} \frac{1}{\gamma} j\omega \bar{m} = & \left[(M_x + m_x) \hat{x} + m_y \hat{y} + (M_z + m_z) \hat{z} \right] \\ & \times \left[\text{[illegible]} + \left(\frac{H_a}{M_s} (M_z + m_z) + H_z \right) \hat{z} \right]. \end{aligned} \tag{17}$$

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Expending the above equation yields

$$\frac{j\omega m_x}{\gamma} - m_y\left(H_z + H_a\alpha_z\right) + \alpha_z H_a m_y = 0 \tag{18a}$$

$$\begin{aligned}\frac{j\omega m_y}{\gamma} - m_z H_x + m_x H_z + m_x H_a \alpha_z \\ - M_z H_x + M_x H_z + \frac{H_a M_z M_x}{M_s} = 0\end{aligned} \tag{18b}$$

$$\frac{j\omega m_z}{\gamma} - \alpha_x H_a m_y + m_y H_x = 0 . \tag{18c}$$

Equating the dc terms in Eq. (18b) to zero yields

$$\frac{\alpha_z}{\alpha_x} = \frac{H_z + H_a \alpha_z}{H_x} . \tag{19}$$

The above equation, together with Eq.(10), enables us to solve for α_x and α_z, and so determine the static equilibrium position of the magnetization.

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The resonance equation can be determined by setting the determinant of Eq. (18) to zero, including only the rf terms, i.e.,

$$\begin{vmatrix} H_z + H_a \alpha_z & \frac{j\omega}{\gamma} & H_a \alpha_x - H_x \\ 0 & H_x - \alpha_x H_a & j\omega \\ \frac{j\omega}{\gamma} & -H_z & 0 \end{vmatrix} = 0. \qquad (20)$$

This yields

$$H_z (H_z + H_a \alpha_z) + (H_x - H_a \alpha_x)^2 = \left(\frac{\omega_r}{\gamma}\right)^2. \qquad (21)$$

We use ω_r in Eq.(21) instead of ω for the same reason as given in connection with Eq. (12).

CALCULATION OF LINEWIDTH

Uniaxial Ferrites

Consider a sphere of nonoriented uniaxial ferrite, whose linewidth it is desired to measure. The biasing field is applied along the Z' direction, and the rf magnetic field along the Y' direction. The biasing field H_o is varied to obtain a resonance curve.

Also consider a particular crystallite whose C axis is oriented at an angle ψ' to the Z' axis, as shown in Fig. 4. For the purpose of determining the resonance condition of this crystallite, it is necessary to express the biasing field in terms of components parallel to or perpendicular to the C axis. These correspond respectively to H_z and H_x of Eqs. (9) and (12). From Fig. 4, we note that

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$$H_z = H_0 \cos\psi$$

$$H_x = H_0 \sin\psi . \qquad (22)$$

For a particular set of values of H_a, H_0, and ω, there is only one value of ψ at which exact resonance is obtained, i.e., where $\omega = \omega_r$ exactly. However, let us permit ψ to vary a little on either side of the value at which exact resonance is obtained, and determine the difference $\delta = (\omega_r - \omega)/|\gamma|$ as a function of ψ. This is plotted in Fig. 5 for a value of H_a = 8500 oersteds, and $|\omega/\gamma|$ = 10,500 oersteds for several values of H_0. From Fig. 5, we note that for a crystallite whose C axis is aligned along the direction of the biasing field $\psi = 0$, the biasing field required for resonance is 2000 oersteds.

We will now assume that if $|\delta|$ is less than some chosen value ϵ, the crystallite will absorb energy, and so reduce the Q of the cavity. Furthermore, we will make the simplifying assumption that all the crystallites that are oriented so that $|\delta| \leq \epsilon$ absorb an equal amount of energy. Also, it is assumed that any crystallite that is oriented so that $|\delta| > \epsilon$ will not absorb any energy from the cavity, and will not affect the cavity Q. The choice of a value for ϵ is somewhat arbitrary. A value of 200 was chosen for convenience in calculation.

For a particular value of H_0, let ψ_1 be the value of ψ at which $\delta = +\epsilon$, and let ψ_2 be the value of ψ at which $\delta = -\epsilon$. For this value of H_0, the number of crystallites that will absorb energy is proportional to the angle subtended between the cones defined by ψ_1 and ψ_2; i.e., to $\int_{\psi_2}^{\psi_1} \sin\psi \, d\psi$. Thus, the absorption and hence the loss component of the susceptibili χ'' are proportional to the above integral. A plot of the relative value of χ'' is shown in Fig. 1. The abscissa in Fig. 1 is the shifted biasing field $H_0 - H_r$, where H_r is the field required for resonance for a crystallite oriented in such a way that its easy direction is parallel to the biasing field. From Fig. 1, we see that the linewidth is approximately 2800 oersteds.

Figure 1 was replotted with values of ϵ taken as 400 and 100 oersteds. In both cases, it was found that the curve of relative absorption differed very little from the curve for ϵ = 200 oersteds. Thus, in this case, the linewidth was substantially independent of the choice of ϵ.

If H_x, H_z, and H_a were all multiplied by a common factor, it is apparent from Eq. (9) and (10) that α_x and α_z would be unchanged, and it is apparent from Eq. (12) that ω_r would be multiplied by the same

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factor. Hence, if we choose values of H_a and $|\omega/\gamma|$ of 8500A oersteds and 10,500A oersteds, respectively, where A is some numerical factor, Fig. 5 will apply, provided δ and the values of H_o are each multiplied by A. Since, as noted above, the shape of the curve of relative absorption is relatively little affected by the value chosen for ϵ, the linewidth will be proportional to the factor A.

Planar Ferrites

Consider a sphere of nonoriented planar ferrite whose linewidth it is desired to measure. The biasing field H_o is applied along the Z' axis, and the rf magnetic field along the Y' axis. The biasing field is varied to obtain a resonance curve.

Consider a particular cyrstallite whose C axis is oriented at an angle ψ with respect to the Z' axis, as shown in Fig. 4. For the purpose of determining the resonance of this crystallite, it is necessary to express the biasing field in terms of components parallel to or perpendicular to the easy plane. These correspond, respectively, to H_z and H_x of Eq. (19) and (21). From Fig. 4, we note that

$$
\begin{aligned}
H_z &= H_o \sin \psi \\
H_x &= H_o \cos \psi .
\end{aligned}
\qquad (23)
$$

We now proceed in the same manner as we did in the case of the uniaxial ferrites. For a particular set of values of H_a, H_o, and ω, there is only one value of ψ at which exact resonance is obtained. However, let us permit ψ to vary a little on either side of the value at which exact resonance is obtained, and determine the difference $\delta = (\omega_r - \omega)/|\gamma|$ as a function of ψ. This is plotted in Fig. 6 for a value of H_a = 9000 oersteds, and $|\omega/\gamma|$ = 5000 oersteds for a series of values of H_o. Similarly, Fig. 7 shows δ as a function of ψ for H_a = 9000 oersteds and $|\omega/\gamma| =$ [illegible] oersteds. From Fig. 6 and 7, we note that for a crystallite oriented so that its easy plane is parallel to the biasing field ($\psi = 90^\circ$), the biasing field required for resonance is 2210 oersteds in the case of Fig. 6 and 9000 oersteds in the case of Fig. 7.

Again, as in the case of the uniaxial ferrites, we will assume that if $|\delta|$ is less than some chosen value ϵ, the crystallite will absorb energy and so reduce the Q of the cavity, and that all such crystallites will absorb an equal amount of energy. Also any crystallite that is oriented so that $|\delta| > \epsilon$ will be assumed not to absorb any energy from the cavity.

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Let us take ϵ = 200 oersteds, and define ψ_1 and ψ_2 as in the case of the uniaxial ferrites. The absorption and hence the loss component of susceptibility χ'' are proportional to

$$\int_{\psi_1}^{\psi_2} \sin\psi \, d\psi.$$

We note that ψ_1 and ψ_2 are interchanged in this case when compared to the corresponding expression for uniaxial ferrites. Plots of the relative absorption are given in Fig. 2. The abscissa in Fig. 2 is the shifted biasing field $H_o - H_r$ where H_r is the field required for resonance for a crystallite oriented so that its easy plane is parallel to the biasing field. As noted above, H_r = 2210 and 9000 oersteds for the cases where $|\omega/\gamma|$ = 5000 and 12,750 oersteds, respectively.

In the case of uniaxial ferrites, it was noted that the linewidth was relatively insensitive to the value of ϵ. This is not so in the case of planar ferrites. For example, for ϵ = 200 oersteds, the linewidth, as can be seen from Fig. 2, is 600 oersteds. However, if ϵ were chosen as 100 oersteds, the linewidth would be 400 oersteds.

As in the case of the uniaxial ferrites, Fig. 6 and 7 will also apply for the case where H_a and $|\omega/\gamma|$ are both multiplied by a factor A, provided the values ϵ and of H_o are also multiplied by A. Since the linewidth varies with ϵ, the linewidth will vary as A^n, where n lies between zero and 1.

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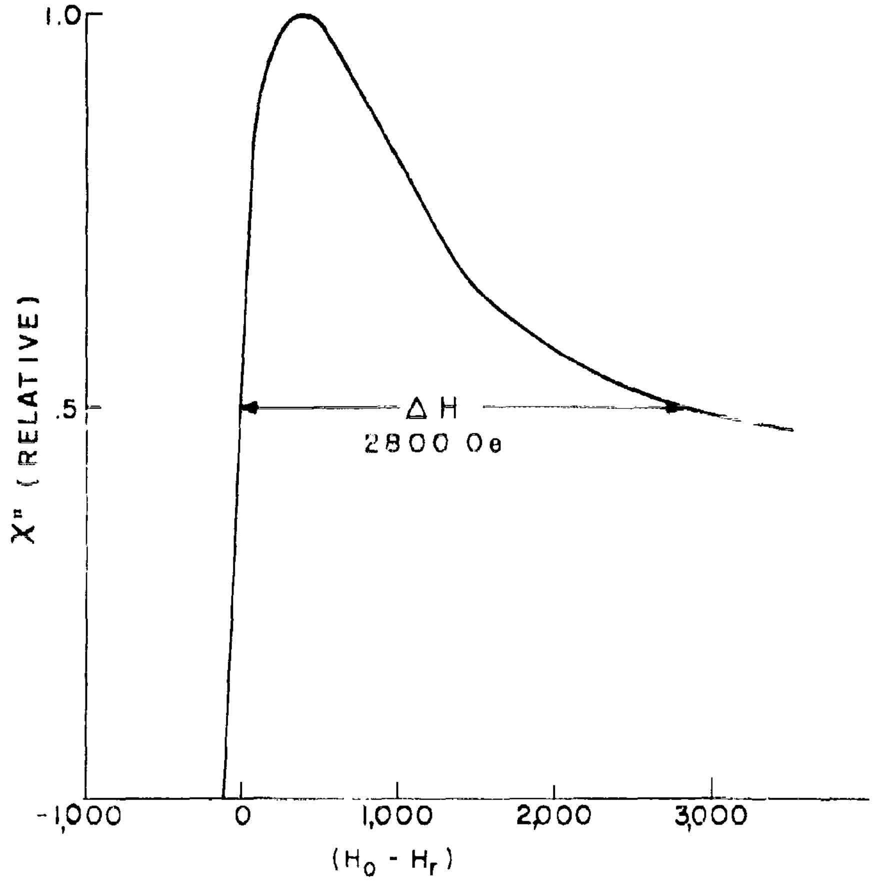

FIG I PLOT OF X"(RELATIVE) VS SHIFTED BIASING FIELD FOR A UNIAXIAL FERRITE WITH H_a = 8,500 OERSTEDS, ω / γ = 10,500 OERSTEDS, H_r = 2,000 OERSTEDS.

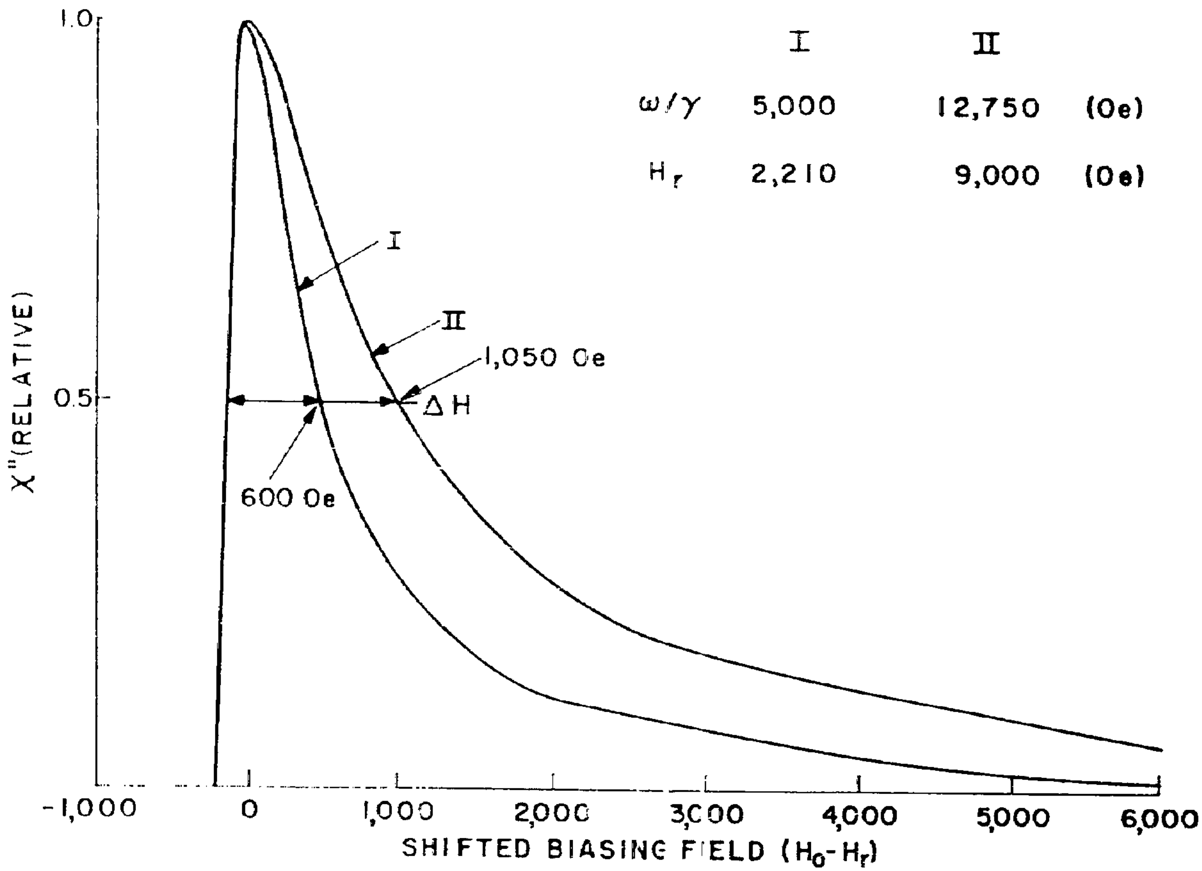

FIG 2 PLOT OF χ'' (RELATIVE) VS SHIFTED BIASING FIELD FOR PLANAR FERRITE WITH H_0= 9,000 OERSTEDS. ω/γ=5,000 AND 12,750 OERSTEDS.

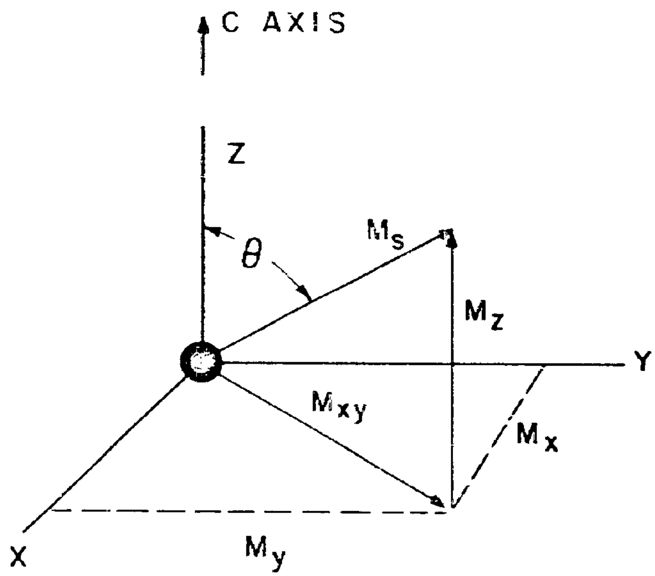

FIG 3 CRYSTALLITE WITH MAGNETIZATION AT AN ANGLE θ WITH RESPECT TO C AXIS.

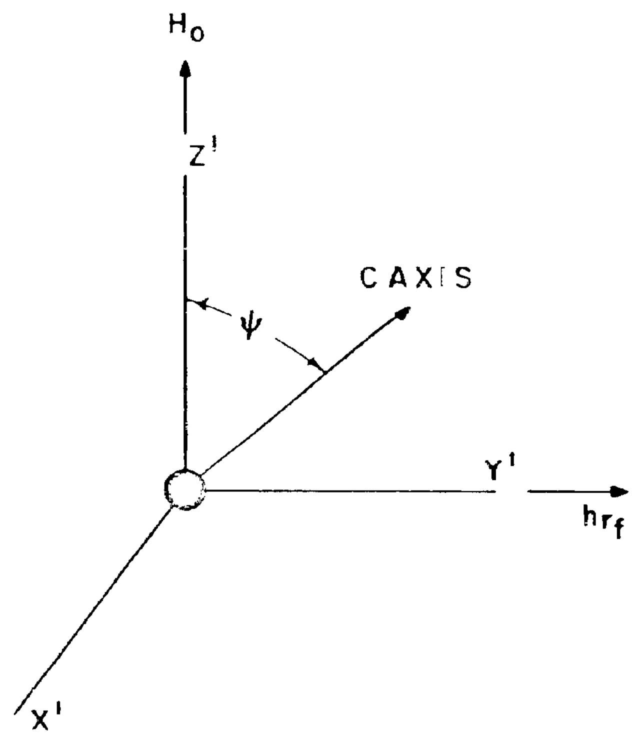

FIG 4 CRYSTALLITE WITH C AXIS AT AN ANGLE ψ WITH RESPECT TO THE BIASING FIELD. BIASING FIELD IS APPLIED PARALLEL TO Z'AXIS, AND THE rf MAGNETIC FIELD IS APPLIED PARALLEL TO Y' AXIS.

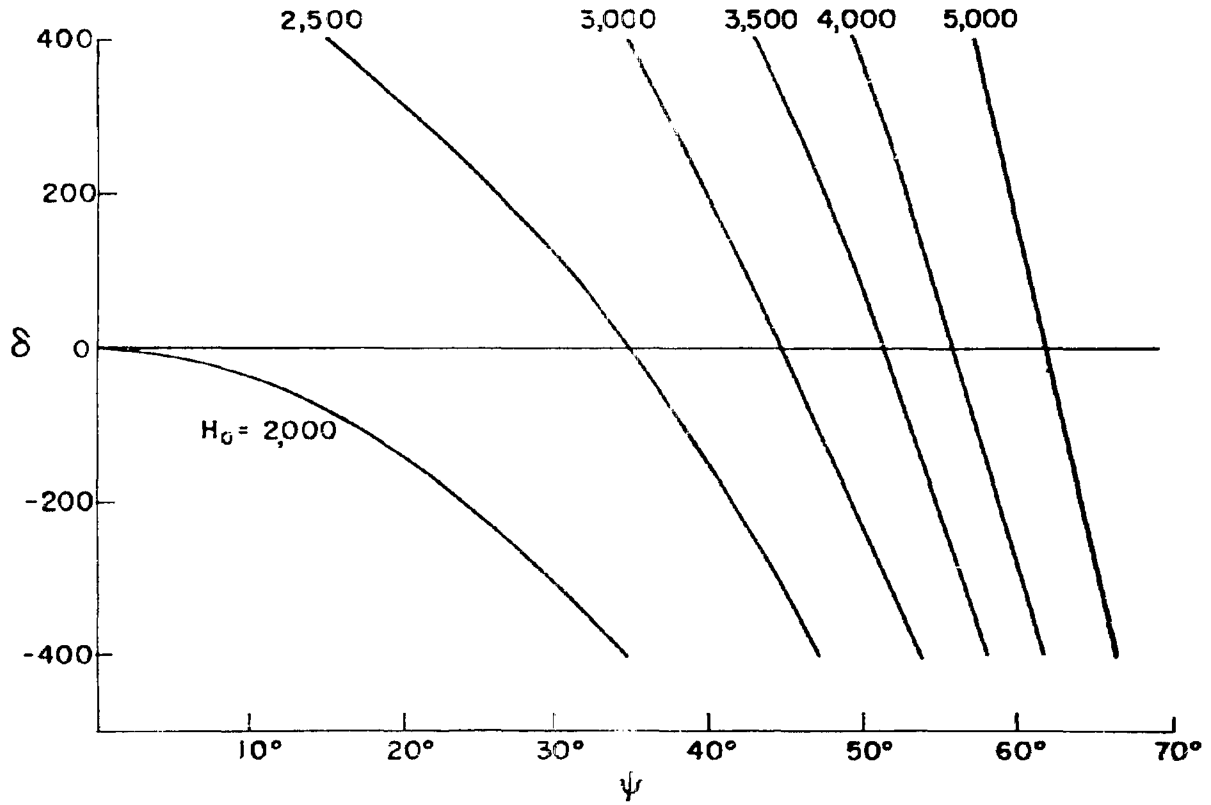

FIG 5 δ VS ψ FOR UNIAXIAL FERRITE WITH H_a = 8,500 OERSTEDS AND ω/γ = 10,500 OERSTEDS.

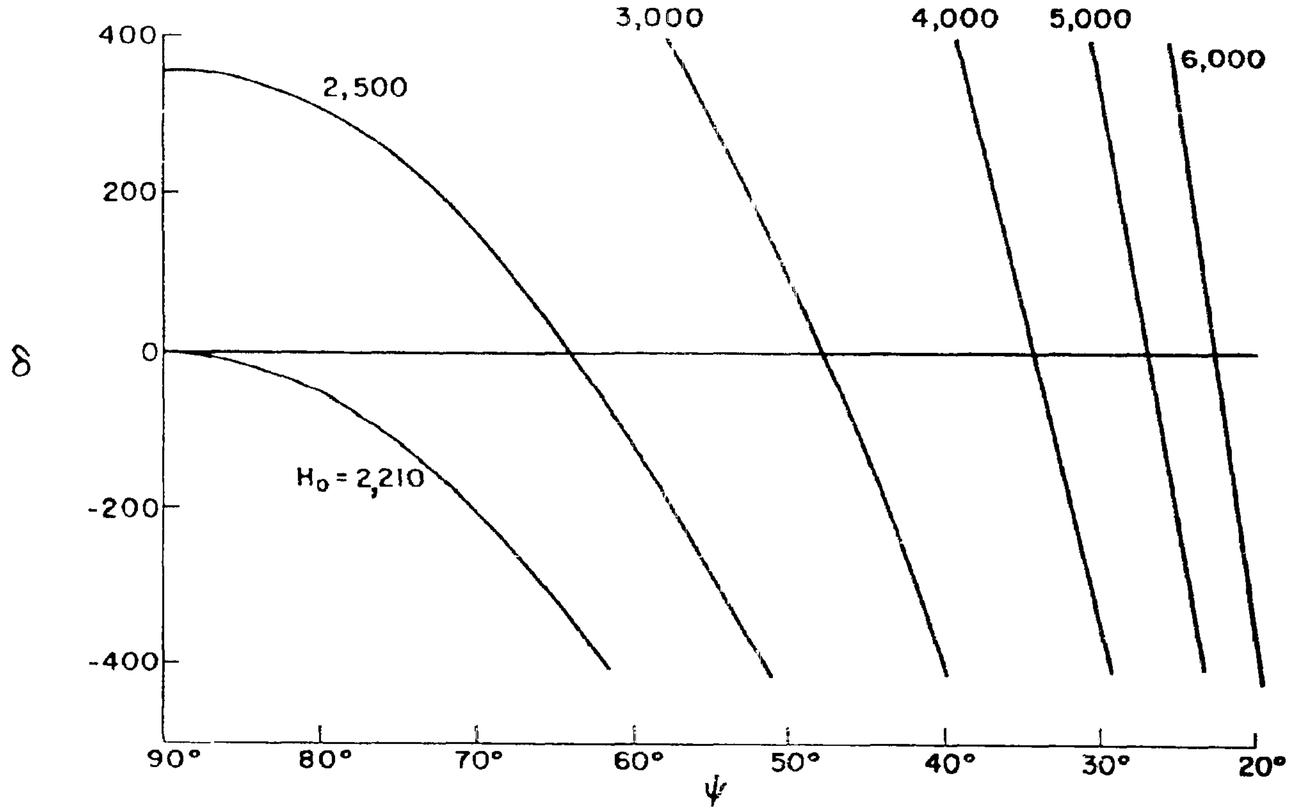

FIG 6 δ VS ψ FOR PLANAR FERRITE WITH H_a = 9,000 OERSTEDS AND ω/γ = 5,000 OERSTEDS.

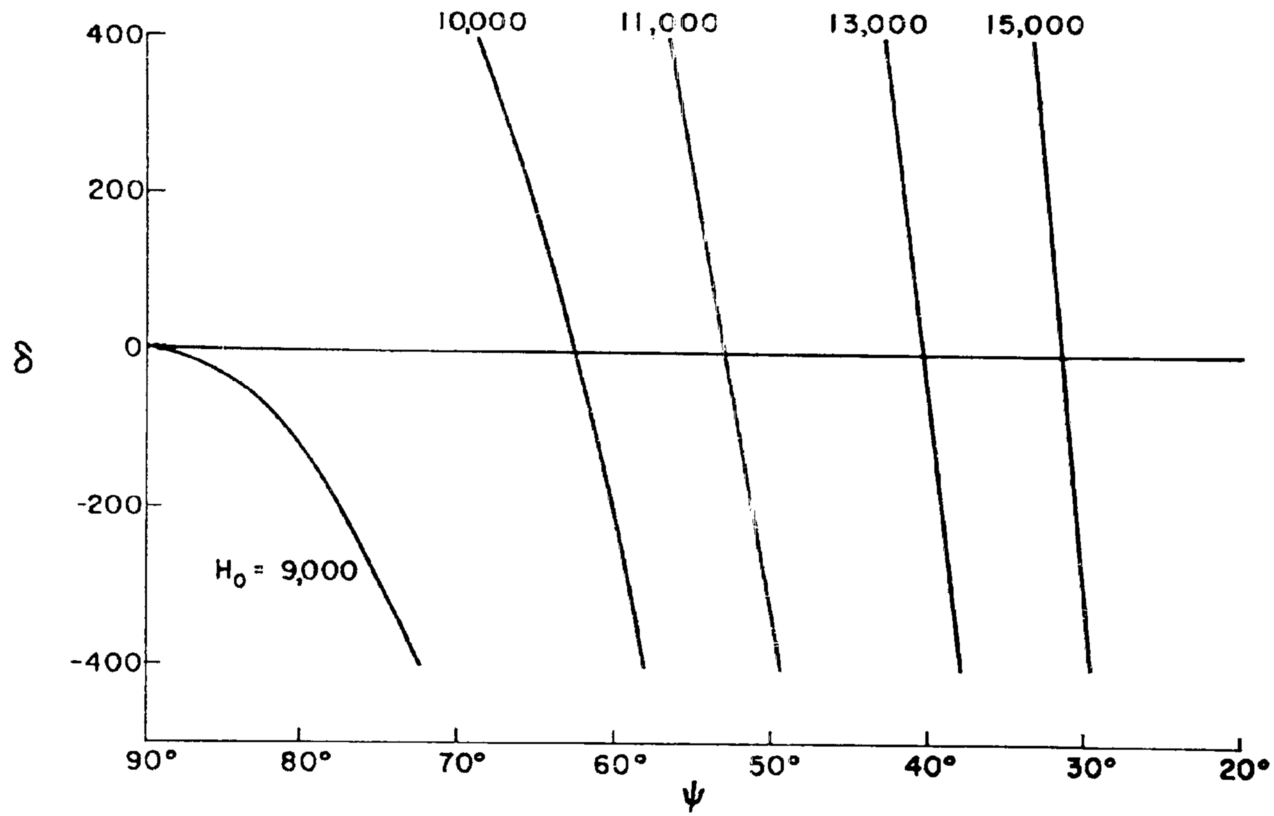

FIG 7 δ VS ψ FOR PLANAR FERRITE WITH H_a = 9,000 OERSTEDS AND ω/γ = 12,750 OERSTEDS

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LINEWIDTH OF NONORIENTED POLYCRYSTALLINE HEXAGON FERRITES WITH LARGE MAGNETIC ANISOTROPY FIELDS, by Isidore Bady, Gilbert McCall. Mar 63, 21 p. incl. illus. 5 refs. (AELRDL Technical Report 2350) (DA Task 3A99-15-006-02) Unclassified report

Theoretical calculations are made of the linewidth of nonoriented, polycrystalline, hexagonal ferrites with large magnetic anisotropy fields, including both uniaxial and planar ferrites. It is shown that the linewidth of a nonoriented uniaxial ferrite is considerably wider than that of a nonoriented planar ferrite. Since imperfect orientation is a major contributor to the linewidth of oriented hexagonal ferrites, it is seen that imperfect orientation will affect the linewidth of uniaxial ferrites far more than that of planar ferrites. This is supported by test data which show that nonoriented planar ferrites can have a linewidth considerably narrower than the narrowest linewidth obtained with oriented uniaxial ferrites.

1. Ferromagnetic Resonance
2. Ferrites
3. Hexagonal Ferrites

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